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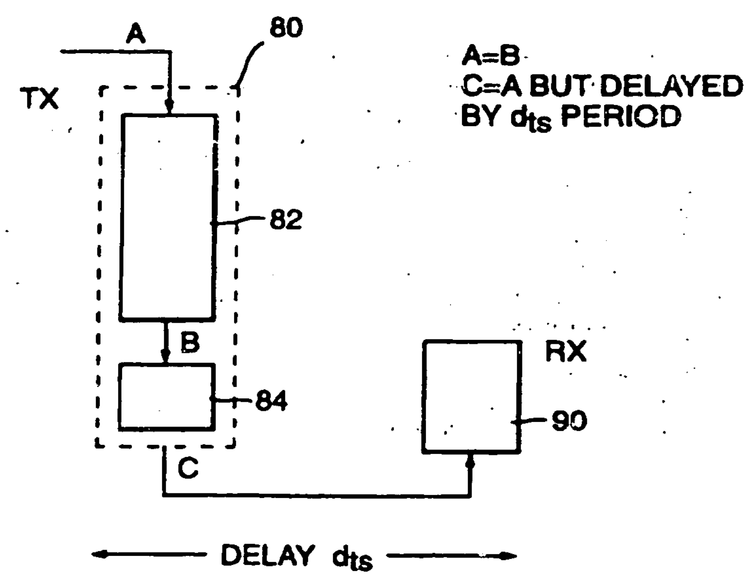
(54) Title: BUFFER CONTROL IN A CODED DATA TRANSMISSION SYSTEM

(57) Abstract

According to one aspect of the present invention there is provided a method of changing the throughput of data in a digital data transmission system, comprising, monitoring the rate of data input to an encoder buffer to determine the decoder buffer requirements downstream; and controlling the encoder buffer in response to the monitoring step such that a change in the rate of data output from the encoder is lagged by a predetermined time period from any change in rate of data input to the encoder buffer. This predictive technique achieves the requirement of instantly changing bitrate in a seamless manner. A seamless bitrate change implies that there is no break in the decoding of the bitstream at the receiver, and also no abnormal artefacts at the receiver. Therefore to change bitrate seamlessly the receiver buffer should not be overflowed or underflowed, and the time stamp offset in the bitstream (the rate buffer delay) should remain constant so that the receiver need not gain or skip frames.



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BUFFER CONTROL IN A CODED DATA TRANSMISSION SYSTEM

This invention relates to improvements in data transmission, particularly in the transmission of digitally encoded data.

A typical system for transmitting and/or receiving digital data may allow several video, audio and associated services to be multiplexed, sent over a single digital transmission channel, received and subsequently decoded. This is the type of system which might operate under the MPEG II standard. The number of services and hence the cost of transmission bandwidth per service is determined by the bitrate. Any improvement in picture quality or reduction in bitrate is thus very important to a service provider.

Improvements in bitrate and quality have been achieved using a Statistical Multiplexing approach as is described in our co-pending application GB9517130.2. In this application the bitrate of data through individual channels or encoders is varied depending on the overall resources available to the system as a whole. By grouping encoders together in "Stat Mux groups", and making real time decisions about the bitrate requirements for those encoders, bitrate can be allocated to maximise picture quality for the group.

Clearly if the bitrate is continually changing the management of data storage in buffers at both transmitter and receiver ends is important. The storage buffers are found either just after the encoder or just before the decoder.

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One of the main problems which is encountered with the present systems, either in fixed mode or Statistical Multiplexing mode, is the problem of changing the bitrate. Typically when systems attempt to change the bitrate there is either an increase or decrease of the data rate. This change in data rate can result in either an overflow or underflow of the decoder buffer, which can cause problems in the receiver in the production of a picture.

The present invention addresses the problems of managing the data within encoder and decoder buffers for systems that are operating both in Statistical Multiplexing mode or in standard fixed bitrate, variable quality mode. In particular the invention deals with the problems of changing the bitrate of the system whilst preserving picture quality, and preventing decoder buffer overflow and underflow.

According to one aspect of the present invention there is provided a method of transmitting data in a digital data transmission system, comprising, monitoring the rate of data input to an encoder buffer to determine the decoder buffer requirements downstream form the encoder buffer; and controlling the encoder buffer in response to the monitoring step to delay a change in the rate of data output from the encoder by a predetermined time period relative to any change in rate of data input to the encoder buffer.

This predictive technique achieves the requirement of instantly changing bitrate in a seamless manner. A seamless bitrate change implies that there is no break in the decoding of the bitstream at the receiver, and also no abnormal artefacts at the receiver. Therefore to change bitrate seamlessly the receiver buffer should not be overflowed or underflowed, and

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the time stamp offset in the bitstream (the rate buffer delay) should remain constant so that the receiver need not gain or skip frames.

Advantageously the output of data is delayed by a time period dependant on the time taken for the data to enter the encoder and leave the decoder buffers. In a preferred example this time period is set to the time stamp of the decoder.

According to a second aspect of the present invention there is provided apparatus for transmitting data in a digital data transmission system, comprising monitoring means for monitoring the rate of data input to an encoder buffer to determine the decoder buffer requirements downstream of the encoder buffer; and a controller for controlling the encoder buffer in response to the monitoring step to delay a change in the rate of data output from the encoder by a predetermined time period relative to any change in rate of data input to the encoder buffer.

Reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a broadcasting system according to the invention;

Figure 2 is a diagram of encoder and decoder buffers;

Figure 3 is a diagram for illustrating the features of the encoder buffer;

Figure 4 is a diagram for illustrating how to achieve seamless bitrate changes according to a first embodiment of the present invention;

Figure 5 is a diagram for illustrating buffer management in a statistical multiplexing system;

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Figure 6 is a diagram for illustrating the effect on buffer occupancy of different frame types;

Figure 7 is a graph for showing the relationship between the encoder pre-quantisation scaling parameter and linear quality; and

Figure 8 is a diagram for illustrating how to achieve seamless bitrate changes according to a second embodiment of the present invention.

The broadcasting system is illustrated in Figure 1 and includes a statistical multiplexing system 10. The statistical multiplexing system may be as described in the above mentioned co-pending application or may be any other type of statistical multiplexing system. A signal 12, such as a video signal is encoded by one of a plurality of encoders 14 and passes through the statistical multiplexing system and a transmission signal 16 is generated. Typically the video signal will be compressed by the encoder The transmission signal is then transmitted to a receiver 18 where it is decoded back into a video signal by one of a plurality of decoders 20. This video signal may then either be displayed for viewing or re-transmitted to another receiver, if necessary. In the figure 1 system, the transmission from the transmission end to the receiver end is via a satellite 22. Clearly other means of transmission could be used in place of satellite transmission. The encoders and decoders each include a buffer 13 and 23 respectively which are described in greater detail below.

The system in figure 1 shows a statistical multiplexing (Stat Mux) system. However, it is to be understood that in certain circumstances the user may not wish to operate the broadcasting system in a 'Stat Mux' mode,

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but in a fixed mode. It is possible to operate the system in either mode as is clear from below.

An MPEG receiver or decoder buffer is limited to 1.8Mbits or greater in size. This rate buffer can sustain a certain amount of bitrate variation. However it cannot support an unlimited variation of bitrate without an underflow or overflow occurring in the decoder buffer. The present invention provides a technique for improving the range of seamless bitrate changes by managing the encoder rate buffer so that the receiver buffer limits are not infringed.

Figure 2 shows the encoder and decoder rate buffers 24 and 27 respectively. As previously mentioned the MPEG standard specifies that the maximum receiver rate buffer size is 1.8 Mbit. In order to prevent underflowing or overflowing of any receiver fitted with an MPEG standard decoder buffer the encoder must also assume the maximum rate buffer of 1.8Mbit. The encoder buffer itself comprises two parts, a rate buffer 25 and a storage area 26 below the rate buffer. This storage area is referred to herein as the stuffing buffer and has an upper level which is referred to as the stuffing level. The stuffing level is equivalent to the virtual floor of the rate buffer which will be described in greater detail below. The rate buffer is the part of the encoder buffer used to smooth the arrival of data. In the case of compressed video data the data arrives at a 'bursty' rate. The rate buffer is provided in the encoder to smooth this bursty data into a near constant stable output bitrate.

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A feedback mechanism exists from the rate buffer to the video compressor (not shown), such that if more data passes into the buffer than is leaving then the buffer fills. As the rate buffer fills a higher quantisation factor Q_P is selected. The effect of this is that less data passes into the rate buffer. A mapping then takes place between the encoder rate buffer occupancy and the quantisation factor. The higher the occupancy, the higher is the mapping. Thus when the rate buffer is empty the lowest quantisation factor of 1 is selected and when the rate buffer is full the highest quantisation factor is selected.

Transferring compressed data from the input of the encoder buffer to the point where it is extracted from the decoder buffer takes a specific length of time. This time is known as the dt_s delay and is forced by the timestamping. The timestamp is associated with a given frame of data and is used by the receiver to identify which frame should be removed from the decoder buffer and decompressed next. The decoder time stamp is selected such that the amount of data in the system is split between the encoder and decoder buffers. The total amount of data in the encoder and decoder buffers is given by:

$$\text{total data} = dt_s \text{ delay} \times \text{bitrate} \qquad 1$$

A reciprocal relationship exists between the occupancy of the encoder rate buffer and the decoder rate buffer. As the encoder rate buffer fills the decoder rate buffer empties and vice versa. Thus the maximum size of the encoder rate buffer is the same as that of the decoder buffer, to prevent overflow and underflow at the receiver.

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The total amount of data in the system at any point in time can also be expressed in terms of the amount and type of buffer capacity. In other words the total amount of data is equal to the buffer space available in both the rate buffer and the so called stuffing buffer, i.e.:

total data = stuffing buffer capacity + rate buffer capacity

Since the rate buffer capacity is equal to 1.8Mbit in an MPEG II compatible system:

total data = stuffing buffer capacity + 1.8Mbit **2**

1 into **2** gives:

stuffing buffer capacity = (dt_s delay x bitrate) - 1.8Mbit

The value of dt_s delay can be varied by the user or by a control computer within the system, however it is preferred that this variable is left unchanged. Accordingly in order to change the bitrate it has been determined that it is necessary to alter the stuffing buffer capacity.

The ability to change the bitrate from one value to another has long been sought. The present invention provides a so called seamless bitrate change which has the following features.

a) A change of bitrate that does not result in a crash (underflow or overflow) of the receiver;

b) A bitrate change that does not modify the dt_s delay i.e. the timestamp offset on the video, so that the receiver need not gain or skip frames; and

c) A bitrate change that does not result in excess encoding artefacts.

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Seamless bitrate changes can be achieved either instantly or over a period of time and the range of an instantaneous bitrate change can be calculated. For a given encoder rate buffer size, dt_s delay and stuffing buffer size the instantaneous maximum bitrate that can be determined:

$$BITRATE_{MAXI\ INST} = \frac{RATE\ BUFFER\ SIZE + STUFFING\ BUFFER\ SIZE}{d_{ts}} \qquad 3$$

The minimum bitrate that can occur instantaneously is dependant on the encoder buffer occupancy. The more data in the encoder buffers, the higher the minimum bitrate. The minimum bitrate is given by:

$$B_{min\,inst} = \frac{Encoder\ Occupancy}{dt_s}$$

This describes the lowest bitrate that can be achieved instantly and does not cause underflow of the receiver buffer.

To achieve bitrates outside of these instantaneous ranges defined above, gradual bitrate changes can be used in which the bitrate change takes place in finite steps. From formula 3 and given that dt_s delay is fixed, rate buffer size is limited to a maximum of 1.8M bit, then:

$$BITRATE_{MAXI} = \frac{1.8 \times 10^6 + STUFFING\ BUFFER\ SIZE}{d_{ts}}$$

If the capacity of the stuffing buffer is increased then higher maximum bitrates can be achieved. In practice the capacity of the stuffing buffer can be increased without limit at a rate of 100Kbits/frame. It will be appreciated that other rates may also be used depending on the system requirements.

The mechanism for increasing the stuffing buffer capacity is shown with reference to Figure 3. The encoder buffer 24 includes the two sections

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previously identified, namely the rate buffer 25 and the 'stuffing buffer' 26. The encoder rate buffer is provided with a virtual floor 54 and ceiling 56. The whole of the rate buffer is typically fixed in absolute size, but is capable of sliding up and down within the encoder buffer itself. Sliding the rate buffer 25 gradually upwards, simultaneously increases the bitrate of the channel. This sliding up of the rate buffer forces more data into the encoder buffer because the quantisation factor Q_P recedes naturally for a given occupancy as the rate buffer slides up.

Figures 4a, 4b, 4c and 4d illustrates one embodiment for carrying out the function of the seamless bitrate change. For the purposes of this explanation it is assumed that the rate of data in is equal to the rate of data out. It will of course be appreciated that this may not be the case, since neither the receiver buffer limits and their effects, or the effect of the quantisation factor on data in are being taken into consideration. In figure 4a normal levels of the rate buffer (RB) and stuffing buffer (SB) are shown. The data is at a quantisation factor of Q_a within the rate buffer. If the incoming data changes it may be necessary to transmit data to the decoder at a higher bitrate. If this higher bitrate is greater than that which can be achieved instantly, then it will be necessary to increase the capacity of the stuffing buffer. If this is the case, the rate buffer slides up the encoder buffer, thereby increasing the capacity of the stuffing buffer. Since in this example the data level remains unchanged, the effect of this is that the quantisation factor will lower. In other words $Q_a > Q_b$, although the total amount of data in the system is the same. As the requirements for still higher bitrates occur the rate

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buffer slides still further up the encoder buffer, making the stuffing buffer still larger. If the rate of data in and out remains the same, $Q_a > Q_b > Q_c$. If the bitrate requirements drop, then the rate buffer can gradually slip down to be in the position shown in Figure 4d. Here the quantisation factor Q_d of the data is very high.

Simultaneously bitrates lower than those that can be achieved instantly can be selected by decreasing the stuffing buffer to a minimum of 0. After this still lower bitrates can be achieved by reducing the size of the rate buffer to less than 1.8 Mbits.

An example of the possible variations is shown below with respect to figure 3, where:

$$
\begin{aligned}
Max\ Inst\ Bitrate &= \frac{1800000 + 200000}{d_{ts}} \\
&= \frac{2000000}{0.5} \\
&= 4000000\, bits/s
\end{aligned}
$$

If an instantaneous bitrate change to 8 Mbits were required this could be achieved from a bitrate of 2000000 bits/s in steps of 100 Kb/frame i.e. 6000000/100000 i.e. 60 steps in 60 frame periods. A bitrate of 8 Mbits/s would require a stuffing buffer given by :

stuffing buffer = bitrate x d_{ts}-delay = rate buffer

+ (8000000 + 0.5) - 1800000

= 2.2 Mbits.

The lowest possible bitrate is dependant on what size rate buffer is felt to be acceptable but typically 0.5 Mbits should be acceptable. Therefore for the

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above example the minimum rate buffer = 0.5 Mbit and minimum stuffing buffer = 0 Mbits.

In a fixed rate system the buffer management must be taken into account to ensure that the system operates satisfactorily. The major features which must be taken into account are as follows: the fact that the decoder buffer has a finite size; a seamless bitrate change is required (i.e. no visual effect or decoder crash); and since I frames generally generate large amounts of data, to prevent multiple changes of Q_p (the encoder pre-quantisation scaling parameter) within a single I frame the encoder is allowed to fill. If this latter point is not taken into consideration, subjectively poor results often result.

In a Statistical Multiplexing (Stat Mux) system, the buffer time delay is generally already allocated and cannot be varied or controlled for buffer management purposes. The Stat Mux system will initialise the buffer levels in such a way that it is able to jump equally well to higher or lower bitrates and still retain adequate data to be able to smooth I frames. It is necessary to balance the bitrate swing with the I frame smoothing. In addition it is preferable to have as little data as possible stored in the encoder, since residual data in the encoder can also inhibit the bitrate swing. Typically about 0.6Mbit are required for I frame smoothing and accordingly the decoder should be split and the decoder buffer level centred at that point. Thus a Stat Mux system with a 2 Mbit decoder buffer would be initialised with a decoder level of 1.3Mbit. The bitrate that creates this initial level will be determined by the Multiplexer code. Assuming the buffer delay is fixed by time stamping

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then the decoder and encoder levels can be calculated. For example, in a system in which the Stat Mux computer decides that 8Mbit/s is the best estimate for bitrate and T is 0.2s, then the buffer levels would be as shown in Figure 5. The bitrate B could jump from a maximum bitrate of 11.5Mbit/s to a minimum of 4.5Mbit/s as is described above.

After each adjustment of the bitrate the value of Q_p must be reallocated, since each bitrate adjustment must be assumed to be the last. This must be done to ensure that during I frames the encoder buffer does not overfill causing the decoder to empty. By following the technique detailed above it is possible to ensure that bitrate does not fall to a level at which the new maximum encoder data level (Q_p = 31) becomes lower than the current data level. If this were to happen then the integrity of the data would be at risk.

A second embodiment of the present invention is now described with reference to figure 8. As in the previous embodiment the encoder buffer 80 includes two parts. These are the rate buffer 82 and a variable or stuffing buffer 84. Also indicated on the diagram are the bitrates A, B, and C at various points in the encoder buffer. Bitrate A is the bitrate of data entering the encoder or rate buffer, bitrate B is the bitrate from the rate buffer to the variable buffer and bitrate C is the bitrate leaving the encoder or variable buffer. The encoder buffer is controlled such that the amount of data leaving the rate buffer is always equal to the amount of data entering the rate buffer. In other words bitrate A is equal to bitrate B. As with previous embodiments of the invention it is not possible to know how the bitrate into the encoder

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